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(54) **RESOURCE PROVISIONING USING PREDICTIVE MODELING IN A NETWORKED COMPUTING ENVIRONMENT**

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***G06T 11/20*** (2006.01)

(52) **U.S. Cl.**
CPC ............. ***G06T 11/206*** (2013.01); ***G06T 11/203*** (2013.01)

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USPC .................... 345/440, 440.1, 440.2, 441, 442
See application file for complete search history.

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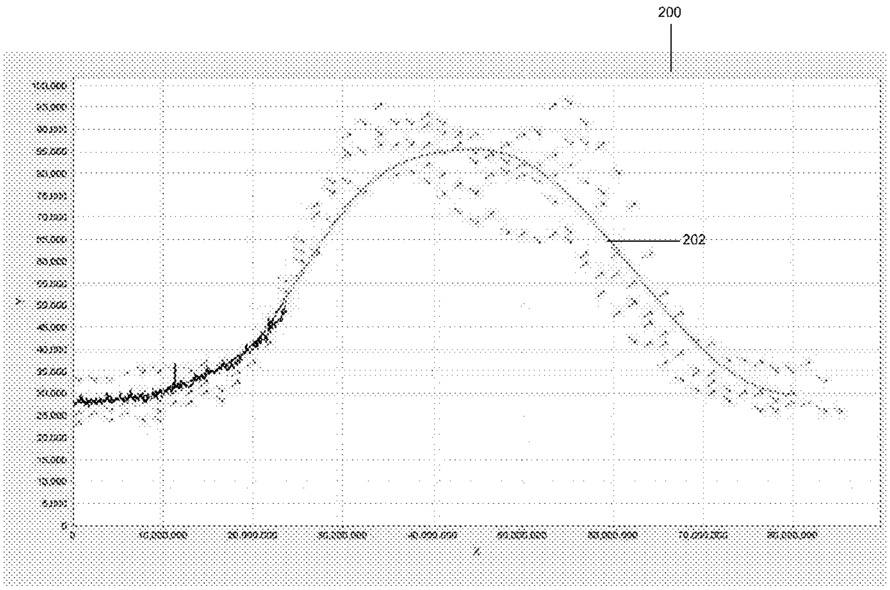
*Primary Examiner* — Jin-Cheng Wang
(74) *Attorney, Agent, or Firm* — William E. Schiesser; Keohane & D'Alessandro PLLC; Hunter E. Webb

(57) **ABSTRACT**

An approach is provided for allowing a network computing (e.g., cloud computing) infrastructure to modify its resource allocation plan (e.g., an instance count) by using a Kth derivative vector plot, which may be generated using historical logs. Among other things, this approach enables an infrastructure to project an allocation forecast for a specified duration and adapt to changes in network traffic.

**22 Claims, 7 Drawing Sheets**



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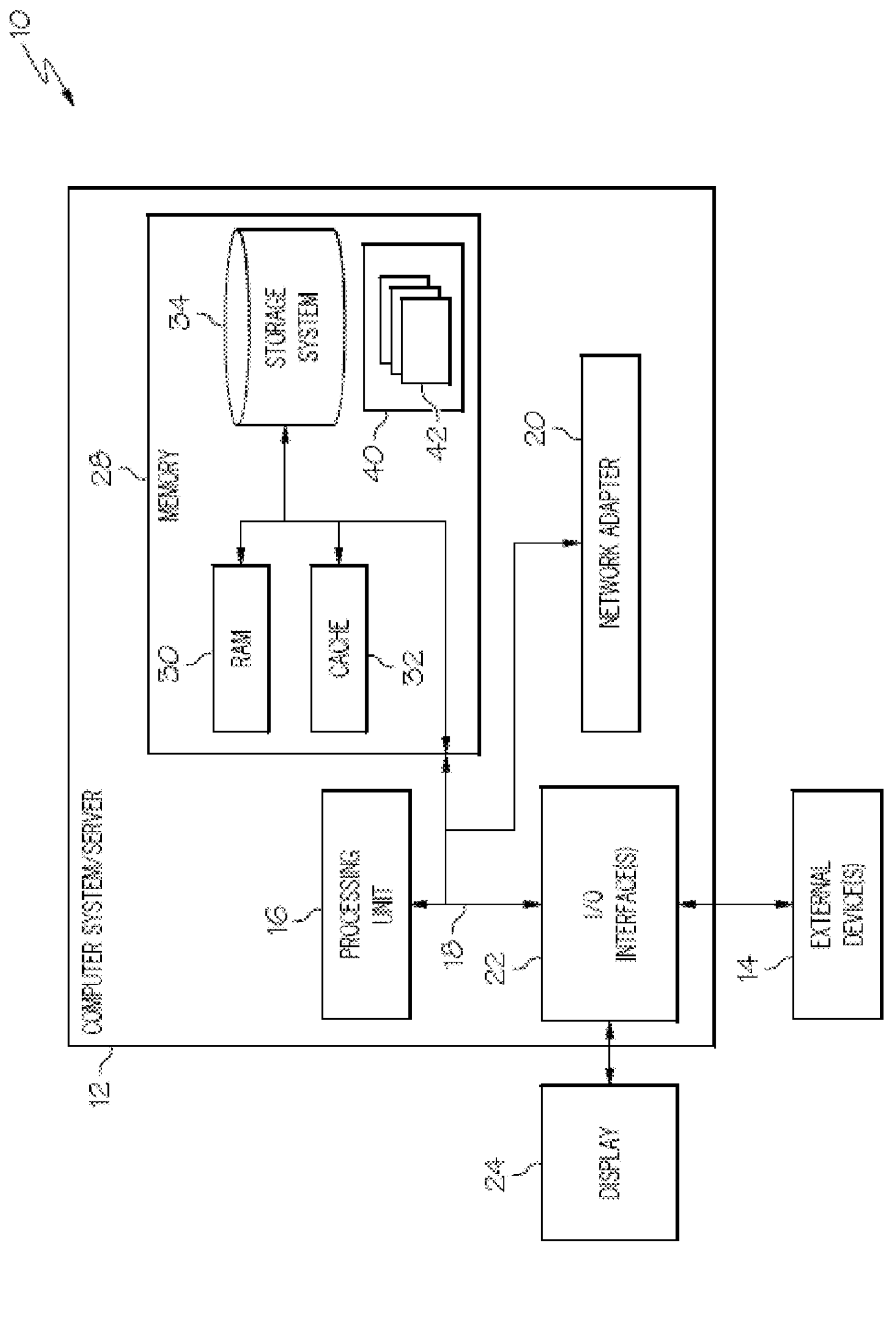

10
12
COMPUTER SYSTEM/SERVER
28
MEMORY
30
RAM
32
CACHE
34
STORAGE SYSTEM
40
42
16
PROCESSING UNIT
18
20
NETWORK ADAPTER
22
I/O INTERFACE(S)
14
EXTERNAL DEVICE(S)
24
DISPLAY

FIG. 1

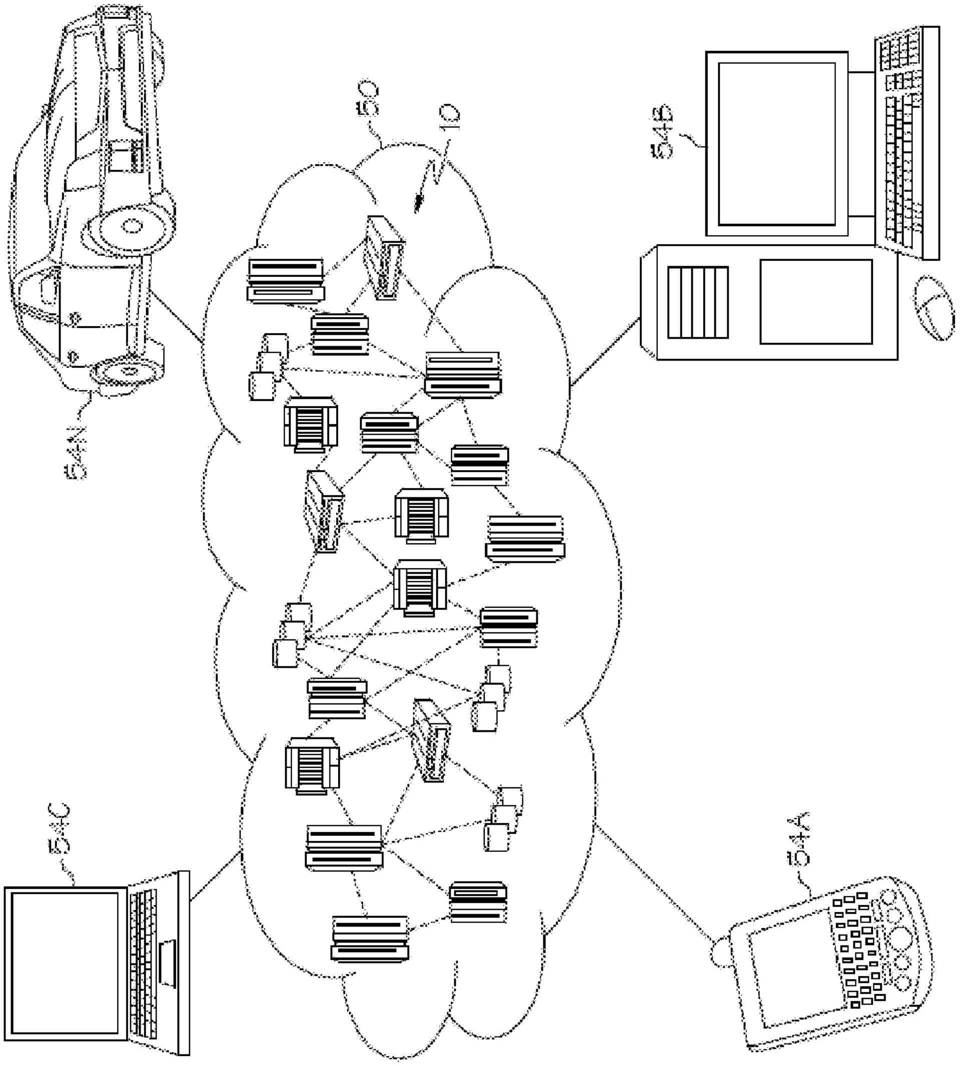
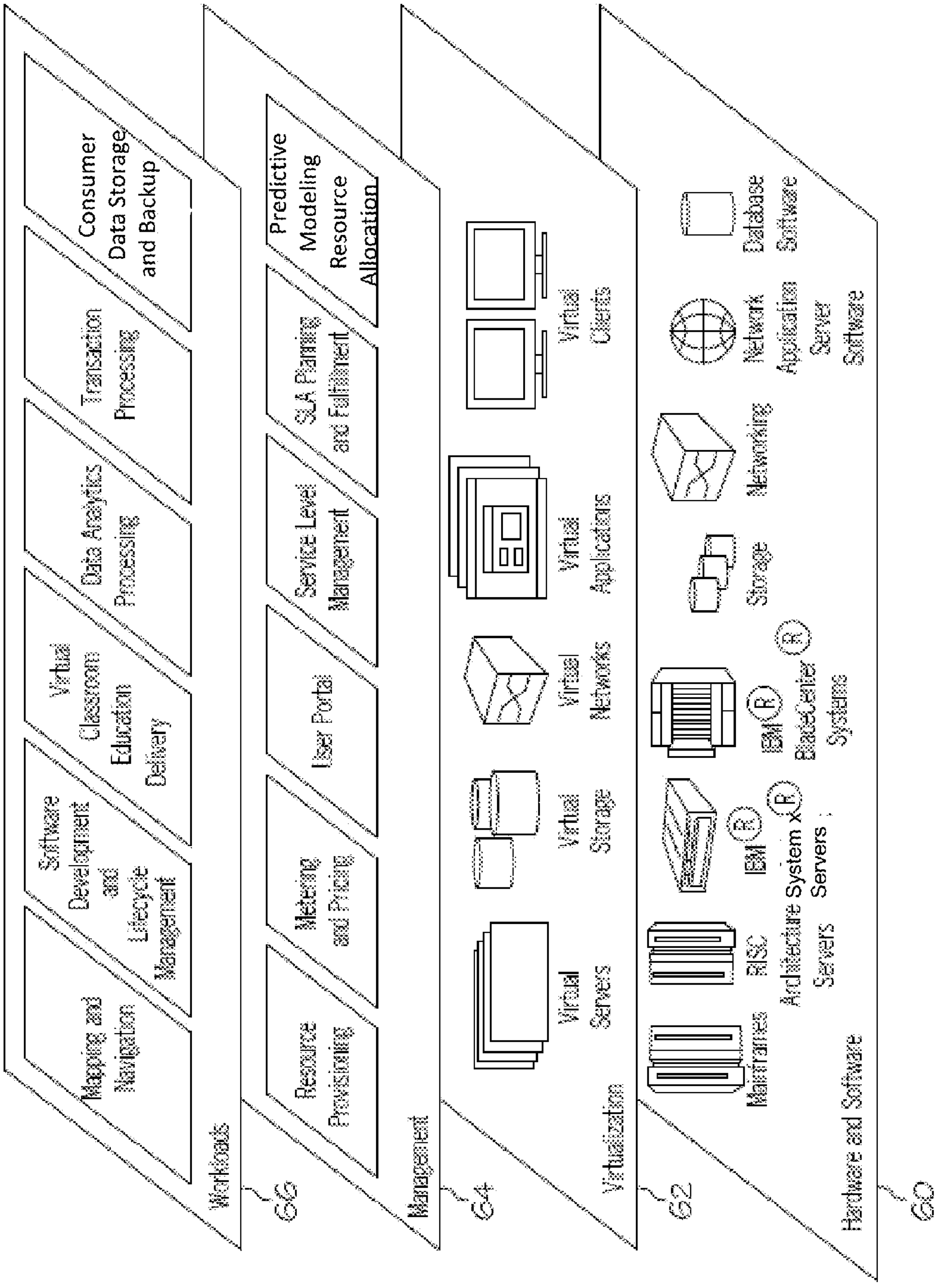


FIG. 2


Workloads
66
Mapping and Navigation
Software Development and Lifecycle Management
Virtual Classroom Education Delivery
Data Analytics Processing
Transaction Processing
Consumer Data Storage and Backup
Management
64
Resource Provisioning
Metering and Pricing
User Portal
Service Level Management
SLA Planning and Fulfillment
Predictive Modeling Resource Allocation
Virtualization
62
Virtual Servers
Virtual Storage
Virtual Networks
Virtual Applications
Virtual Clients
Hardware and Software
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Mainframes
RISC Architecture Servers
IBM® System x® Servers
IBM® BladeCenter® Systems
Storage
Networking
Network Application Server Software
Database Software

FIG. 3

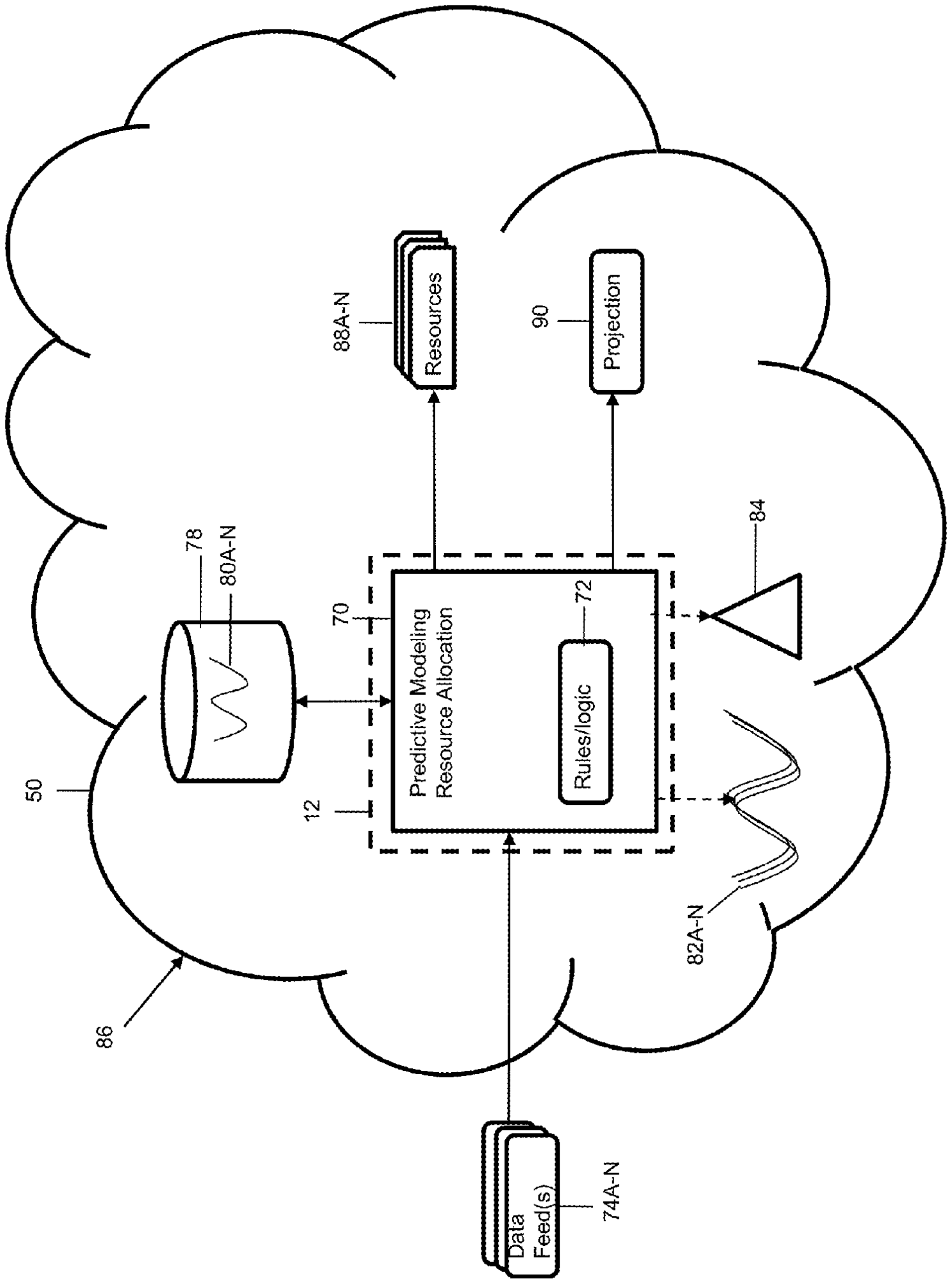
86
50
12
70
Predictive Modeling
Resource Allocation
78
80A-N
Rules/logic
72
88A-N
Resources
90
Projection
84
82A-N
Data
Feed(s)
74A-N

FIG. 4

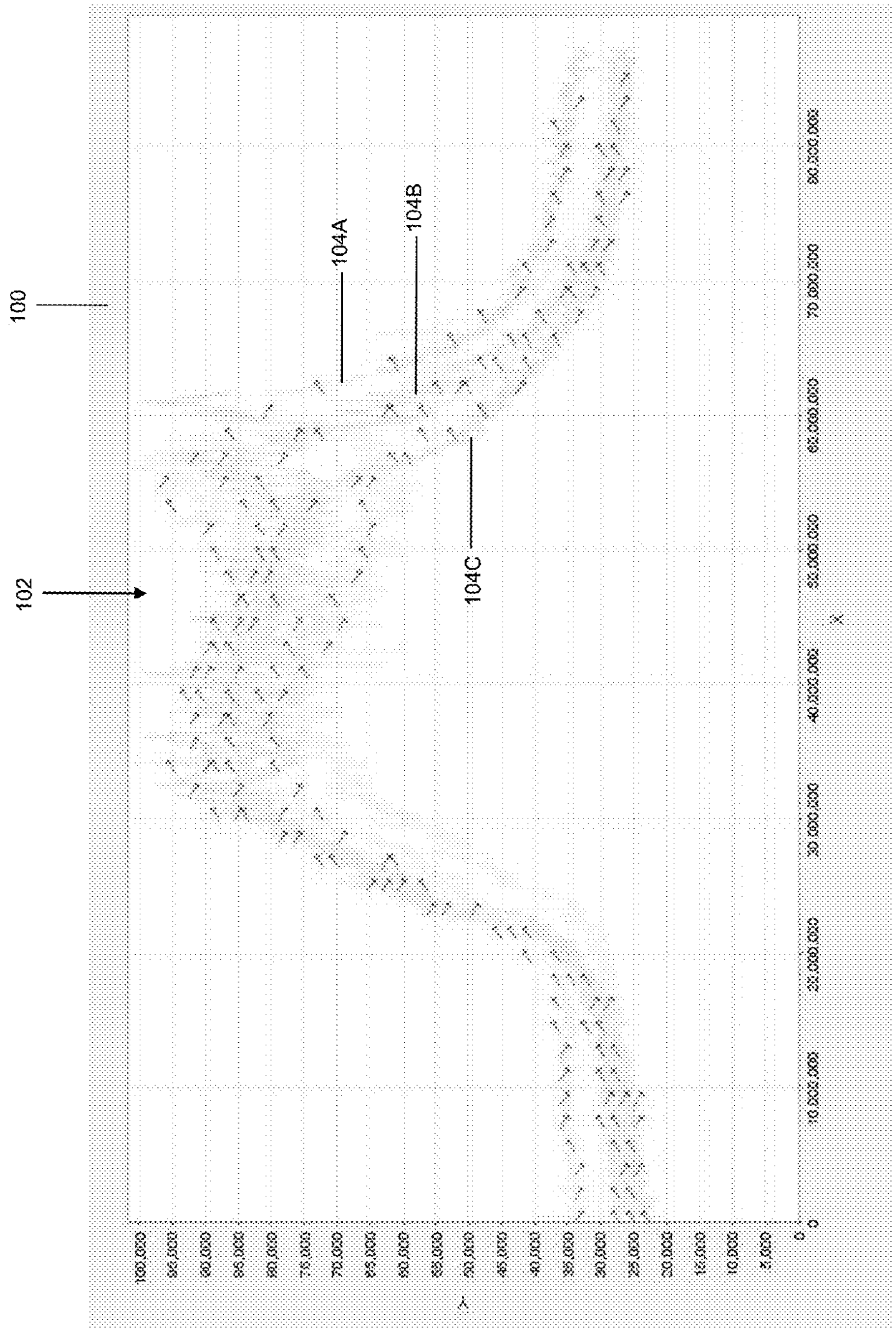
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FIG. 5

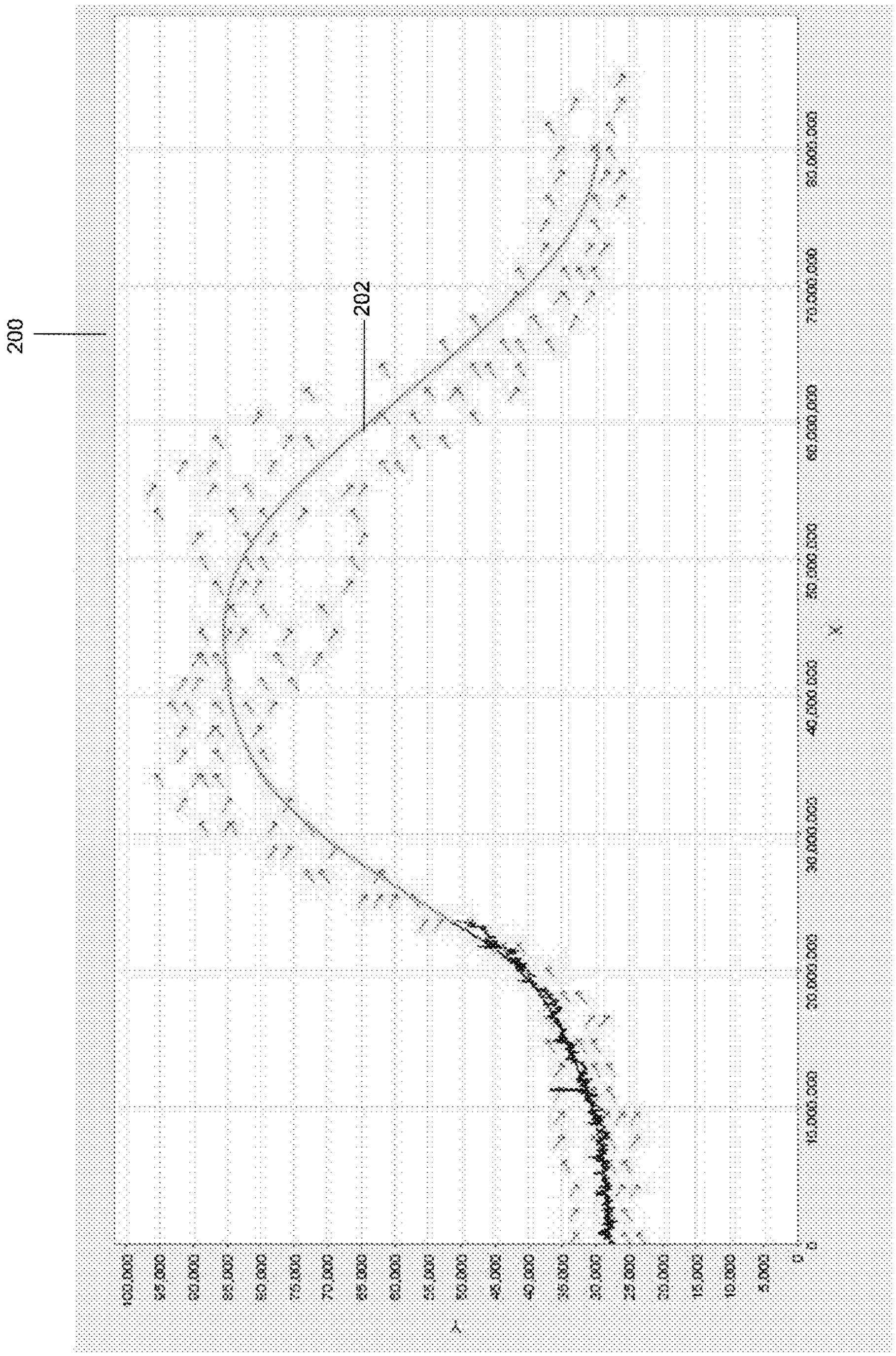
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FIG. 6

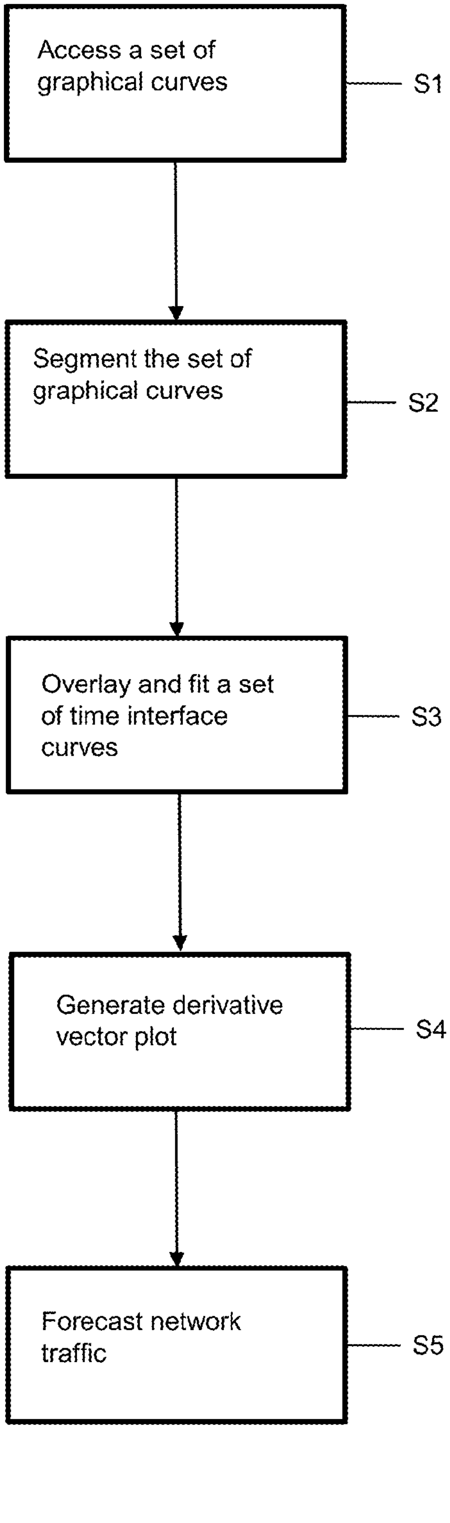
Access a set of graphical curves
S1
Segment the set of graphical curves
S2
Overlay and fit a set of time interface curves
S3
Generate derivative vector plot
S4
Forecast network traffic
S5

FIG. 7

# RESOURCE PROVISIONING USING PREDICTIVE MODELING IN A NETWORKED COMPUTING ENVIRONMENT

## TECHNICAL FIELD

Embodiments of the present invention relate to computing resource allocation in a networked computing environment (e.g., a cloud computing environment). Specifically, embodiments of the present invention relate to the utilization of historical web access logs and generation of a derivative vector plot (e.g., $K^{th}$ derivative vector plot) that is used to provide forecasts of future events.

## BACKGROUND

The networked computing environment (e.g., cloud computing environment) is an enhancement to the predecessor grid environment, whereby multiple grids and other computation resources may be further enhanced by one or more additional abstraction layers (e.g., a cloud layer), thus making disparate devices appear to an end-consumer as a single pool of seamless resources. These resources may include such things as physical or logical computing engines, servers and devices, device memory, and storage devices, among others.

Cloud services may be rendered through dynamic infrastructure provisioning. For example, within a relatively static hardware pool, operating systems and applications may be deployed and reconfigured to meet dynamic customer computational demands. Within a cloud environment's boundaries, images may be installed and overwritten, Internet Protocol (IP) addresses may be modified, and real and virtual processors may be allocated to meet changing business needs. Challenges may exist, however, in providing an infrastructure that is capable of modifying its resource allocation plan/protocol in response to changing demands.

## SUMMARY

Embodiments of the present invention provide an approach for allowing a network computing (e.g., cloud computing) infrastructure to modify its resource allocation plan (e.g., an instance count) by using a $K^{th}$ derivative vector plot, which may be generated using historical logs. Among other things, this approach enables an infrastructure to project an allocation forecast for a specified duration and adapt to changes in network traffic.

A first aspect of the present invention provides a computer-implemented method for provisioning computing resources using predictive modeling in a networked computing environment, comprising: accessing a set of graphical curves of network data traffic versus time, the set of graphical curves being stored in at least one computer storage device; segmenting the set of graphical curves into a set of predetermined time intervals to yield a set of time interval curves; overlaying and fitting the set of time interval curves to yield a set of best fit overlaying curves; generating a derivative vector plot based on a set of data points of the set of best fit overlaying curves; and forecasting network traffic in the networked computing environment based on the derivative vector plot.

A second aspect of the present invention provides a system for provisioning computing resources using predictive modeling in a networked computing environment, comprising: a memory medium comprising instructions; a bus coupled to the memory medium; and a processor coupled to the bus that when executing the instructions causes the system to: access a set of graphical curves of network data traffic versus time, the set of graphical curves being stored in at least one computer storage device; segment the set of graphical curves into a set of predetermined time intervals to yield a set of time interval curves; overlay and fit the set of time interval curves to yield a set of best fit overlaying curves; generate a derivative vector plot based on a set of data points of the set of best fit overlaying curves; and forecast network traffic in the networked computing environment based on the derivative vector plot.

A third aspect of the present invention provides a computer program product for provisioning computing resources using predictive modeling in a networked computing environment, the computer program product comprising a computer readable storage media, and program instructions stored on the computer readable storage media, to: access a set of graphical curves of network data traffic versus time, the set of graphical curves being stored in at least one computer storage device; segment the set of graphical curves into a set of predetermined time intervals to yield a set of time interval curves; overlay and fit the set of time interval curves to yield a set of best fit overlaying curves; generate a derivative vector plot based on a set of data points of the set of best fit overlaying curves; and forecast network traffic in the networked computing environment based on the derivative vector plot.

A fourth aspect of the present invention provides a method for deploying a system for provisioning computing resources using predictive modeling in a networked computing environment, comprising: providing a computer infrastructure being operable to: access a set of graphical curves of network data traffic versus time, the set of graphical curves being stored in at least one computer storage device; segment the set of graphical curves into a set of predetermined time intervals to yield a set of time interval curves; overlay and fit the set of time interval curves to yield a set of best fit overlaying curves; generate a derivative vector plot based on a set of data points of the set of best fit overlaying curves; and forecast network traffic in the networked computing environment based on the derivative vector plot.

## BRIEF DESCRIPTION OF THE DRAWINGS

These and other features of this invention will be more readily understood from the following detailed description of the various aspects of the invention taken in conjunction with the accompanying drawings in which:

FIG. **1** depicts a cloud computing node according to an embodiment of the present invention.

FIG. **2** depicts a cloud computing environment according to an embodiment of the present invention.

FIG. **3** depicts abstraction model layers according to an embodiment of the present invention.

FIG. **4** depicts a system diagram according to an embodiment of the present invention.

FIG. **5** depicts a set of overlaid plots/curves according to an embodiment of the present invention.

FIG. **6** depicts a derivative vector plot according to an embodiment of the present invention.

FIG. **7** depicts a method flow diagram according to an embodiment of the present invention

The drawings are not necessarily to scale. The drawings are merely schematic representations, not intended to portray specific parameters of the invention. The drawings are intended to depict only typical embodiments of the invention, and therefore should not be considered as limiting the scope of the invention. In the drawings, like numbering represents like elements.

## DETAILED DESCRIPTION

Illustrative embodiments will now be described more fully herein with reference to the accompanying drawings, in which embodiments are shown. This disclosure may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete and will fully convey the scope of this disclosure to those skilled in the art. In the description, details of well-known features and techniques may be omitted to avoid unnecessarily obscuring the presented embodiments.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of this disclosure. As used herein, the singular forms "a", "an", and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. Furthermore, the use of the terms "a", "an", etc., do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced items. The term "set" is intended to mean a quantity of at least one. It will be further understood that the terms "comprises" and/or "comprising", or "includes" and/or "including", when used in this specification, specify the presence of stated features, regions, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, regions, integers, steps, operations, elements, components, and/or groups thereof.

Embodiments of the present invention provide an approach for allowing a network computing (e.g., cloud computing) infrastructure to modify its resource allocation plan (e.g., an instance count) by using a $K^{th}$ derivative vector plot, which may be generated using historical logs. Among other things, this approach enables an infrastructure to project an allocation forecast for a specified duration and adapt to changes in network traffic.

It is understood in advance that although this disclosure includes a detailed description of cloud computing, implementation of the teachings recited herein are not limited to a cloud computing environment. Rather, embodiments of the present invention are capable of being implemented in conjunction with any other type of computing environment now known or later developed.

Cloud computing is a model of service delivery for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, network bandwidth, servers, processing, memory, storage, applications, virtual machines, and services) that can be rapidly provisioned and released with minimal management effort or interaction with a provider of the service. This cloud model may include at least five characteristics, at least three service models, and at least four deployment models.

Characteristics are as Follows:

On-demand self-service: a cloud consumer can unilaterally provision computing capabilities, such as server time and network storage, as needed, automatically without requiring human interaction with the service's provider.

Broad network access: capabilities are available over a network and accessed through standard mechanisms that promote use by heterogeneous thin or thick client platforms (e.g., mobile phones, laptops, and PDAs).

Resource pooling: the provider's computing resources are pooled to serve multiple consumers using a multi-tenant model, with different physical and virtual resources dynamically assigned and reassigned according to demand. There is a sense of location independence in that the consumer generally has no control or knowledge over the exact location of the provided resources but may be able to specify location at a higher level of abstraction (e.g., country, state, or datacenter).

Rapid elasticity: capabilities can be rapidly and elastically provisioned, in some cases automatically, to quickly scale out and rapidly released to quickly scale in. To the consumer, the capabilities available for provisioning often appear to be unlimited and can be purchased in any quantity at any time.

Measured service: cloud systems automatically control and optimize resource use by leveraging a metering capability at some level of abstraction appropriate to the type of service (e.g., storage, processing, bandwidth, and active consumer accounts). Resource usage can be monitored, controlled, and reported providing transparency for both the provider and consumer of the utilized service.

Service Models are as Follows:

Software as a Service (SaaS): the capability provided to the consumer is to use the provider's applications running on a cloud infrastructure. The applications are accessible from various client devices through a thin client interface such as a web browser (e.g., web-based email). The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, storage, or even individual application capabilities, with the possible exception of limited consumer-specific application configuration settings.

Platform as a Service (PaaS): the capability provided to the consumer is to deploy onto the cloud infrastructure consumer-created or acquired applications created using programming languages and tools supported by the provider. The consumer does not manage or control the underlying cloud infrastructure including networks, servers, operating systems, or storage, but has control over the deployed applications and possibly application-hosting environment configurations.

Infrastructure as a Service (IaaS): the capability provided to the consumer is to provision processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, deployed applications, and possibly limited control of select networking components (e.g., host firewalls).

Deployment Models are as Follows:

Private cloud: the cloud infrastructure is operated solely for an organization. It may be managed by the organization or a third party and may exist on-premises or off-premises.

Community cloud: the cloud infrastructure is shared by several organizations and supports a specific community that has shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It may be managed by the organizations or a third party and may exist on-premises or off-premises.

Public cloud: the cloud infrastructure is made available to the general public or a large industry group and is owned by an organization selling cloud services.

Hybrid cloud: the cloud infrastructure is a composition of two or more clouds (private, community, or public) that remain unique entities but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load-balancing between clouds).

A cloud computing environment is service oriented with a focus on statelessness, low coupling, modularity, and semantic interoperability. At the heart of cloud computing is an infrastructure comprising a network of interconnected nodes.

Referring now to FIG. **1**, a schematic of an example of a cloud computing node is shown. Cloud computing node **10** is only one example of a suitable cloud computing node and is not intended to suggest any limitation as to the scope of use or functionality of embodiments of the invention described herein. Regardless, cloud computing node **10** is capable of being implemented and/or performing any of the functionality set forth hereinabove.

In cloud computing node **10**, there is a computer system/server **12**, which is operational with numerous other general purpose or special purpose computing system environments or configurations. Examples of well-known computing systems, environments, and/or configurations that may be suitable for use with computer system/server **12** include, but are not limited to, personal computer systems, server computer systems, thin clients, thick clients, hand-held or laptop devices, multiprocessor systems, microprocessor-based systems, set top boxes, programmable consumer electronics, network PCs, minicomputer systems, mainframe computer systems, and distributed cloud computing environments that include any of the above systems or devices, and the like.

Computer system/server **12** may be described in the general context of computer system-executable instructions, such as program modules, being executed by a computer system. Generally, program modules may include routines, programs, objects, components, logic, data structures, and so on that perform particular tasks or implement particular abstract data types. Computer system/server **12** may be practiced in distributed cloud computing environments where tasks are performed by remote processing devices that are linked through a communications network. In a distributed cloud computing environment, program modules may be located in both local and remote computer system storage media including memory storage devices.

As shown in FIG. **1**, computer system/server **12** in cloud computing node **10** is shown in the form of a general-purpose computing device. The components of computer system/server **12** may include, but are not limited to, one or more processors or processing units **16**, a system memory **28**, and a bus **18** that couples various system components including system memory **28** to processor **16**.

Bus **18** represents one or more of any of several types of bus structures, including a memory bus or memory controller, a peripheral bus, an accelerated graphics port, and a processor or local bus using any of a variety of bus architectures. By way of example, and not limitation, such architectures include Industry Standard Architecture (ISA) bus, Micro Channel Architecture (MCA) bus, Enhanced ISA (EISA) bus, Video Electronics Standards Association (VESA) local bus, and Peripheral Component Interconnects (PCI) bus.

Computer system/server **12** typically includes a variety of computer system readable media. Such media may be any available media that is accessible by computer system/server **12**, and it includes both volatile and non-volatile media, removable and non-removable media.

System memory **28** can include computer system readable media in the form of volatile memory, such as random access memory (RAM) **30** and/or cache memory **32**. Computer system/server **12** may further include other removable/non-removable, volatile/non-volatile computer system storage media. By way of example only, storage system **34** can be provided for reading from and writing to a non-removable, non-volatile magnetic media (not shown and typically called a "hard drive"). Although not shown, a magnetic disk drive for reading from and writing to a removable, non-volatile magnetic disk (e.g., a "floppy disk"), and an optical disk drive for reading from or writing to a removable, non-volatile optical disk such as a CD-ROM, DVD-ROM, or other optical media can be provided. In such instances, each can be connected to bus **18** by one or more data media interfaces. As will be further depicted and described below, memory **28** may include at least one program product having a set (e.g., at least one) of program modules that are configured to carry out the functions of embodiments of the invention.

The embodiments of the invention may be implemented as a computer readable signal medium, which may include a propagated data signal with computer readable program code embodied therein (e.g., in baseband or as part of a carrier wave). Such a propagated signal may take any of a variety of forms including, but not limited to, electro-magnetic, optical, or any suitable combination thereof. A computer readable signal medium may be any computer readable medium that is not a computer readable storage medium and that can communicate, propagate, or transport a program for use by or in connection with an instruction execution system, apparatus, or device.

Program code embodied on a computer readable medium may be transmitted using any appropriate medium including, but not limited to, wireless, wireline, optical fiber cable, radio-frequency (RF), etc., or any suitable combination of the foregoing.

Program/utility **40**, having a set (at least one) of program modules **42**, may be stored in memory **28** by way of example, and not limitation, as well as an operating system, one or more application programs, other program modules, and program data. Each of the operating system, one or more application programs, other program modules, and program data or some combination thereof, may include an implementation of a networking environment. Program modules **42** generally carry out the functions and/or methodologies of embodiments of the invention as described herein.

Computer system/server **12** may also communicate with one or more external devices **14** such as a keyboard, a pointing device, a display **24**, etc.; one or more devices that enable a consumer to interact with computer system/server **12**; and/or any devices (e.g., network card, modem, etc.) that enable computer system/server **12** to communicate with one or more other computing devices. Such communication can occur via I/O interfaces **22**. Still yet, computer system/server **12** can communicate with one or more networks such as a local area network (LAN), a general wide area network (WAN), and/or a public network (e.g., the Internet) via network adapter **20**. As depicted, network adapter **20** communicates with the other components of computer system/server **12** via bus **18**. It should be understood that although not shown, other hardware and/or software components could be used in conjunction with computer system/server **12**. Examples include, but are not limited to: microcode, device drivers, redundant processing units, external disk drive arrays, RAID systems, tape drives, and data archival storage systems, etc.

Referring now to FIG. **2**, illustrative cloud computing environment **50** is depicted. As shown, cloud computing environment **50** comprises one or more cloud computing nodes **10** with which local computing devices used by cloud consumers, such as, for example, personal digital assistant (PDA) or cellular telephone **54**A, desktop computer **54**B, laptop computer **54**C, and/or automobile computer system **54**N may communicate. Nodes **10** may communicate with one another. They may be grouped (not shown) physically or virtually, in one or more networks, such as private, community, public, or hybrid clouds as described hereinabove, or a combination thereof. This allows cloud computing environment **50** to offer infrastructure, platforms, and/or software as services for which a cloud consumer does not need to maintain resources on a local computing device. It is understood that the types of computing devices **54**A-N shown in FIG. **2** are intended to be illustrative only and that computing nodes **10** and cloud computing environment **50** can communicate with any type of computerized device over any type of network and/or network addressable connection (e.g., using a web browser).

Referring now to FIG. **3**, a set of functional abstraction layers provided by cloud computing environment **50** (FIG. **2**) is shown. It should be understood in advance that the components, layers, and functions shown in FIG. **3** are intended to be illustrative only and embodiments of the invention are not limited thereto. As depicted, the following layers and corresponding functions are provided:

Hardware and software layer **60** includes hardware and software components. Examples of hardware components include mainframes. In one example, IBM® zSeries® systems and RISC (Reduced Instruction Set Computer) architecture based servers. In one example, IBM pSeries® systems, IBM System x® servers, IBM BladeCenter® systems, storage devices, networks, and networking components. Examples of software components include network application server software. In one example, IBM WebSphere® application server software and database software. In one example, IBM DB2® database software. (IBM, zSeries, pSeries, System x, BladeCenter, WebSphere, and DB2 are trademarks of International Business Machines Corporation registered in many jurisdictions worldwide.)

Virtualization layer **62** provides an abstraction layer from which the following examples of virtual entities may be provided: virtual servers; virtual storage; virtual networks, including virtual private networks; virtual applications and operating systems; and virtual clients.

In one example, management layer **64** may provide the functions described below. Resource provisioning provides dynamic procurement of computing resources and other resources that are utilized to perform tasks within the cloud computing environment. Metering and pricing provide cost tracking as resources are utilized within the cloud computing environment, and billing or invoicing for consumption of these resources. In one example, these resources may comprise application software licenses. Security provides identity verification for cloud consumers and tasks, as well as protection for data and other resources. Consumer portal provides access to the cloud computing environment for consumers and system administrators. Service level management provides cloud computing resource allocation and management such that required service levels are met. Service Level Agreement (SLA) planning and fulfillment provides pre-arrangement for, and procurement of, cloud computing resources for which a future requirement is anticipated in accordance with an SLA. Further shown in management layer is predictive modeling(-based) resource allocation, which represents the functionality that is provided under the embodiments of the present invention.

Workloads layer **66** provides examples of functionality for which the cloud computing environment may be utilized. Examples of workloads and functions which may be provided from this layer include: mapping and navigation; software development and lifecycle management; virtual classroom education delivery; data analytics processing; transaction processing; and consumer data storage and backup. As mentioned above, all of the foregoing examples described with respect to FIG. **3** are illustrative only, and the invention is not limited to these examples.

It is understood that all functions of the present invention as described herein typically may be performed by the predictive modeling resource allocation functionality (of management layer **64**, which can be tangibly embodied as modules of program code **42** of program/utility **40** (FIG. **1**). However, this need not be the case. Rather, the functionality recited herein could be carried out/implemented and/or enabled by any of the layers **60**-**66** shown in FIG. **3**.

It is reiterated that although this disclosure includes a detailed description on cloud computing, implementation of the teachings recited herein are not limited to a cloud computing environment. Rather, the embodiments of the present invention are intended to be implemented with any type of networked computing environment now known or later developed.

Referring now to FIG. **4**, a system diagram describing the functionality discussed herein according to an embodiment of the present invention is shown. It is understood that the teachings recited herein may be practiced within any type of networked computing environment **86** (e.g., a cloud computing environment **50**). A computer system/server **12**, which can be implemented as either a stand-alone computer system or as a networked computer system is shown in FIG. **4**. In the event the teachings recited herein are practiced in a networked computing environment **86**, each client need not have a predictive modeling resource allocation engine (engine **70**). Rather, engine **70** could be loaded on a server or server-capable device that communicates (e.g., wirelessly) with the clients to provide predictive modeling-based resource allocation therefor. Regardless, as depicted, engine **70** is shown within computer system/server **12**. In general, engine **70** can be implemented as program/utility **40** on computer system **12** of FIG. **1** and can enable the functions recited herein. As further shown, engine **70** (in one embodiment) comprises a rules and/or computational engine that processes a set (at least one) of rules/logic **72** and/or provides predictive modeling-based computing resource allocation hereunder.

Along these lines, engine **70** may perform multiple functions similar to a general-purpose computer. Specifically, among other functions, engine **70** may (among other things): receive a set of data feeds **74**A-N; determine network traffic based on the set of data feeds **74**A-N (e.g., social networking feeds); generate a set of graphical curves **80**A-N based on the network traffic (e.g., for storage in one or more computer storage devices **78**); access a set of graphical curves **80**A-N of network data traffic versus time; segment the set of graphical curves **80**A-N into a set of predetermined time intervals to yield a set of time interval curves **82**A-N; overlay and fit the set of time interval curves **82**A-N to yield a set of best fit overlaying curves; generate a derivative vector plot **84** (e.g., a $K^{th}$ derivative vector plot) based on a set of data points of the set of best fit overlaying curves; integrate K initial conditions of a K quantity of times using a predetermined numerical technique (e.g., a fourth order Runge-Kutta technique); forecast network traffic in the networked computing environment **86** based on derivative vector plot **84**; provision a set of computing resources **88**A-N in the networked computing environment based on the forecasted network traffic; and/or output a network traffic projection **90** based on the forecasting.

As can be seen, embodiments of the present invention utilize concepts of predictive modeling and forecasting, vector fields, and/or derivatives. These concepts will be further described below:

Predictive Models and Forecasting

Predictive models analyze past performance to assess the likelihood of a specific event to occur in the future. Similarly, forecasting is the process of making statements about events whose actual outcomes typically have not yet been observed. This category also encompasses models that seek out subtle data patterns for future forecasting. Predictive models often perform calculations during live transactions, and with the advancement in computing speed, modeling systems can effectively be used for forecasting or predictions.

Vector Fields and Derivatives

In calculus, a vector field, or plot, is an assignment of a vector to each point in a subset of Euclidean space. A vector plot in the plane, for instance, may be visualized as a collection of arrows with a given magnitude and direction attached to each point in the plane. In calculus, a derivative is a measurement of how a function changes as its inputs change. A derivative may be thought of as how much one quantity is changing in response to changes in some other quantity. For example, the derivative of a position of a moving object with respect to time is the object's instantaneous velocity. The elements of differential and integral calculus extend to vector fields in a natural way. Vector fields may be thought of as representing the velocity of a moving flow in space.

## Illustrative Example

The embodiments of the present invention may be understood with the following example. It is understood, however, that this example is intended to be illustrative only and not limiting the teachings recited herein. Assume in this example that an events private cloud is provided that is tasked with developing the infrastructure to deliver brand critical web sites such as IBM.com (IBM and related terms are trademarks of International Business Machines Corporation in the United States and/or other countries) to a major sporting event. The embodiments discussed herein may utilize historical web access logs from the duration of such respective events, and generate a $K^{th}$ derivative vector plot that is used to provide forecasts of future similar events. The embodiments of the present invention may enable cloud environments to predict required resource allocations, allocate those resources as required, and modify those resources continuously and accurately.

Along these lines, embodiments of the present invention may utilize mathematical measures, such as differential and integral calculus, and error minimization to generate a $K^{th}$ derivative vector plot. The plot may then be utilized to generate a resource utilization/allocation projection/plan. This may be accomplished as follows:

1. Using each individual day's traffic, create an aggregate best fitting overlay. This may be achieved by minimizing the error in fitting the curves for each day's traffic by using the following steps:
   A. Splice/segment the historical traffic into individual periods. For example, in the events private cloud, the historical traffic may be spliced on local minimums.
   B. Overlay the resulting curves and minimize the error in fitting the curves. For example, in the events private cloud, an error function may be defined as the integral of the square of the ordinate distance between interpolated traffic curves. This may be minimized by varying curve characteristics. More specifically, the events private cloud may use Powell Optimization to minimize the error by altering the amplitudes of the traffic curves, shifting the abscissae, and shifting the ordinates.
   C. Maintain the characteristics that are pertinent by reverting their alterations. For example, in the events private cloud, only the abscissa shift is reflected in the final overlay. The ordinate shift and amplitude changes are reverted.
2. Generate a $K^{th}$ derivative vector for each point on each best-fit overlaying curve. Then, superimpose the vectors onto a unified vector plot at their respective initial abscissa and ordinate. For example, in the events private cloud, a second derivative vector plot is generated from all relevant historical event data.

Forecasting

Based on the generated $K^{th}$ derivative vector plot, the embodiments may then process real time web access log data. The vector plot may take the volume and trend (direction) of the current log data as inputs to output an instantaneous traffic projection for the next period. This may be achieved by taking K initial conditions and integrating K times using a numerical integration technique. For example, in the events private cloud, the current position (abscissa, ordinate) and velocity (slope) are used as initial conditions and a fourth order Runge-Kutta method is applied to the vector plot with sufficiently small time change (Δt) and carried out over a predetermined period (e.g., 24 hours).

Fourth Order Runge-Kutta Method

As indicated above, a $4^{th}$ order Runge-Kutta method (RK4) may be utilized hereunder. Shown below is a brief description of this method.

Let an initial value problem be specified as follows.

$$\dot{y}=f(t,y),y(t_0)=y_0.$$

This expression generally means that the rate at which y changes is a function of y itself and of t (time). At the start, time is $t_0$ and y is $y_0$. In the equation, y may be a scalar or a vector. The RK4 method for this problem may be given by the following equations:

$$y_{n+1} = y_n + \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4)$$
$$t_{n+1} = t_n + h$$

where $y_{n+1}$ is the RK4 approximation of $y(t_{n+1})$, and

$$k_1 = hf(t_n, y_n),$$
$$k_2 = hf\left(t_n + \frac{1}{2}h,\ y_n + \frac{1}{2}k_1\right),$$
$$k_3 = hf\left(t_n + \frac{1}{2}h,\ y_n + \frac{1}{2}k_2\right),$$
$$k_4 = hf(t_n + h,\ y_n + k_3).$$

Thus, the next value ($y_{n+1}$) is determined by the present value ($y_n$) plus the weighted average of four increments, where each increment is the product of the size of the interval h, and an estimated slope specified by function $f$ on the right-hand side of the differential equation. The variables indicated above may be defined as follows:

$k_1$ is the increment based on the slope at the beginning of the interval, using $y_2$ (e.g., Euler's method);

$k_2$ is the increment based on the slope at the midpoint of the interval, using

$$y_n + \frac{1}{2}k_1;$$

$k_3$ is again the increment based on the slope at the midpoint, but now using

$$y_n + \frac{1}{2}k_2;$$

and

$k_4$ is the increment based on the slope at the end of the interval, using $y_n+k_3$, In averaging the four increments, greater weight is given to the increments at the midpoint. The weights are chosen such that if $f$ is independent of y, so that the differential equation is equivalent to a simple integral, then RK4 is Simpson's rule. The RK4 method is a fourth-order method, meaning that the error per step is on the order of $h^5$, while the total accumulated error has order $h^4$.

Derivation of Fourth Order Runge-Kutta Method

In general a Runge-Kutta method of order $\epsilon$ can be written as:

$$y_{t+h} = y_t + h \cdot \sum_{i=1}^{s} a_i k_i + O(h^{s+1})$$

where:

$$k_i = f\left(y_t + h \cdot \sum_{j=1}^{s} \beta_{ij} k_j,\ t_n - \alpha_i h\right)$$

are increments obtained evaluating the derivatives of $y_t$ at the i-th order. We develop the derivation for the Runge-Kutta fourth order method using the general formula with s=4 evaluated, as explained above, at the starting point, the midpoint and the end point of any interval (t,t+h), thus we choose:

$$\begin{array}{ll}
\alpha_i & \beta_i \\
\alpha_1 = 0 & \beta_{21} = \frac{1}{2} \\
\alpha_2 = \frac{1}{2} & \beta_{32} = \frac{1}{2} \\
\alpha_3 = \frac{1}{2} & \beta_{43} = 1 \\
\alpha_4 - 1 &
\end{array}$$

and $\beta_{ij}$=0 otherwise. We begin by defining the following quantities:

$$y^1_{t+h} = y_t + hf(y_t, t)$$

$$y^2_{t+h} = y_t + hf\left(y^1_{t+h/2}, t + \frac{h}{2}\right)$$

$$y^3_{t+h} = y_t + hf\left(y^2_{t+h/2}, t + \frac{h}{2}\right)$$

where

$$y^1_{t+b/2} = \frac{y_t + y^1_{t+h}}{2}$$

and

$$y^2_{t+b/2} = \frac{y_t + y^2_{t+h}}{2}$$

If we define:

$$k_1 = f(y_t, t)$$

$$k_2 = f\left(y^1_{t+h/2}, t + \frac{h}{2}\right)$$

-continued

$$k_3 = f\left(y^2_{t+h/2}, t + \frac{h}{2}\right)$$

$$k_4 = f(y^3_{t+h}, t + h)$$

and for the previous relations we can show that the following equalities holds up to $\mathcal{O}$ ($h^2$):

$$\begin{aligned}
k_2 &= f\left(y^1_{t+h/2}, t + \frac{h}{2}\right) \\
&= f\left(y_t + \frac{h}{2}k_1, t + \frac{h}{2}\right) \\
&= f(y_t, t) - \frac{h}{2}\frac{d}{dt}f(y_t, t)
\end{aligned}$$

$$\begin{aligned}
k_3 &= f\left(y^2_{t+h/2}, t + \frac{h}{2}\right) \\
&= f\left(y_t + \frac{h}{2}f\left(y_t + \frac{h}{2}k_1, t + \frac{h}{2}\right), t + \frac{h}{2}\right) \\
&= f(y_t, t) - \frac{h}{2}\frac{d}{dt}\left[f(y_t, t) + \frac{h}{2}\frac{d}{dt}f(y_t, t)\right]
\end{aligned}$$

$$\begin{aligned}
k_4 &= f(y^3_{t+h}, t \mid h) \\
&= f\left(y_t \mid hf\left(y_t \mid \frac{h}{2}k_{2,}t \mid \frac{h}{2}\right), t \mid h\right) \\
&= f\left(y_t + hf\left(y_t + \frac{h}{2}f\left(y_t + \frac{h}{2}f(y_t, t), t + \frac{h}{2}\right), t + \frac{h}{2}\right), t + h\right) \\
&= f(y_t, t) - h\frac{d}{dt}\left[f(y_t, t) + \frac{h}{2}\frac{d}{dt}\left[f(y_t, t) + \frac{h}{2}\frac{d}{dt}f(y_t, t)\right]\right]
\end{aligned}$$

where:

$$\frac{d}{dt}f(y_t, t) = \frac{\partial}{\partial y}f(y_t, t)\dot{y}_t + \frac{\partial}{\partial t}f(y_t, t) = f_y(y_t, t)\dot{y} + f_t(y_t, t) := \ddot{y}_t$$

is the total derivative of $f$ with respect to time. If we now express the general formula using what we just derived, we obtain:

$$\begin{aligned}
y_{t+h} = y_t \Bigg| h\Big\{a \cdot f(y_t, t) \Big| b \cdot \left[f(y_t, t) \middle| \frac{h}{2}\frac{d}{dt}f(y_t, t)\right] \Bigg| &+ c \cdot \\
\left[f(y_t,t) + \frac{h}{2}\frac{d}{dt}\left[f(y_t, t) + \frac{h}{2}\frac{d}{dt}f(y_t, t)\right]\right] &+ + \\
d \cdot \left[f(y_t, t) + h\frac{d}{dt}\left[f(y_t, t) + \frac{h}{2}\frac{d}{dt}\left[f(y_t, t) + \frac{h}{2}\frac{d}{dt}f(y_t, t)\right]\right]\right]\Big\} &+ \\
O(h^5) = y_t + a \cdot hf_t + b \cdot hf_t + b \cdot \frac{h^2}{2}\frac{d f_t}{dt} &+ \\
c \cdot hf_t + c \cdot \frac{h^2}{2}\frac{d f_t}{dt} + + c \cdot \frac{h^3}{4}\frac{d^2 f_t}{dt^2} + d \cdot hf_t &+ \\
d \cdot h^2\frac{d f_t}{dt} + d \cdot \frac{h^3}{2}\frac{d^2 f_t}{dt^2} + d \cdot \frac{h^4}{4}\frac{d^3 f_t}{dt^3} &+ O(h^5)
\end{aligned}$$

and comparing this with the Taylor series of $y_{t+h}$ around $y_t$:

$$\begin{aligned}
y_{t+h} &= y_t + h\dot{y}_t + \frac{h^2}{2}\ddot{y}_t + \frac{h^3}{6}y_t^{(3)} + \frac{h^4}{24}y_t^{(4)} + O(h^5) = \\
&= y_t + hf(y_t, t) + \frac{h^2}{2}\frac{d}{dt}f(y_t, t) -
\end{aligned}$$

-continued

$$\frac{h^3}{6}\frac{d^2}{dt^2}f(y_t,t)+\frac{h^4}{24}\frac{d^3}{dt^3}f(y_t,t)$$

we obtain a system of constraints on the coefficients:

$$\begin{cases} a+b+c+d=1 \\ \frac{1}{2}b+\frac{1}{2}c+d=\frac{1}{2} \\ \frac{1}{4}c+\frac{1}{2}d=\frac{1}{6} \\ \frac{1}{4}d=\frac{1}{24} \end{cases}$$

which solved gives

$$a=\frac{1}{6},$$
$$b=\frac{1}{3},$$
$$c=\frac{1}{3},$$
$$d=\frac{1}{6}$$

as stated above. It is understood that these computations/algorithms are typically performed/calculated by engine **70**.

Referring now to FIG. **5**, a graph **100** of network traffic rate of requests per minute (y-axis) versus time (x-axis) is shown. In general, graph **100** depicts data points **102** for overlaid time segments (e.g., plots/curves **104**A-C). Segments **104**A-C may pertain to a common time period occurring in consecutive days, weeks, months, etc. By overlaying and fitting plots/curves **104**A-C, data outliers may be reduced and a more accurate depiction of network traffic versus time may be obtained. Specifically, graph **100** represents a second derivative vector that is created at multiple points over each of a set of daily traffic plots **104**A-C (e.g., corresponding to **82**A-N of FIG. **4**). Each of the plots **104**A-C may be superimposed to form a vector field.

Referring now to FIG. **6**, a graph **200** having a single predictive curve/plot **202** is shown. In general, vector plot **200** is generated (e.g., by engine **70** of FIG. **4**) by utilizing a fourth-order Runge-Kutta method to integrate over the second-derivative vector plot **100** of FIG. **5** (e.g., with initial conditions specified by the current traffic) to generate a forecast for the remainder of a period to be generated. Curve **202** allows potential future network traffic to be forested (e.g., extrapolated).

Referring now to FIG. **7**, a method flow diagram according to an embodiment of the present invention is depicted. In step S**1**, a set of graphical curves of network data traffic versus time is accessed. The set of graphical curves may be stored in at least one computer storage devices. In step S**2**, the set of graphical curves is segmented into a set of predetermined time intervals to yield a set of time interval curves. In step S**3**, the set of time interval curves will be overlaid and fitted to yield a set of best fit overlaying curves. In step S**4**, a derivative vector plot will be generated based on a set of data points of the set of best fit overlaying curves. In step S**5**, network traffic in the networked computing environment will be forecasted based on the derivative vector plot.

While shown and described herein as a predictive modeling-based resource allocation solution, it is understood that the invention further provides various alternative embodiments. For example, in one embodiment, the invention provides a computer-readable/useable medium that includes computer program code to enable a computer infrastructure to provide predictive modeling-based resource allocation functionality as discussed herein. To this extent, the computer-readable/useable medium includes program code that implements each of the various processes of the invention. It is understood that the terms computer-readable medium or computer-useable medium comprise one or more of any type of physical embodiment of the program code. In particular, the computer-readable/useable medium can comprise program code embodied on one or more portable storage articles of manufacture (e.g., a compact disc, a magnetic disk, a tape, etc.), on one or more data storage portions of a computing device, such as memory **28** (FIG. **1**) and/or storage system **34** (FIG. **1**) (e.g., a fixed disk, a read-only memory, a random access memory, a cache memory, etc.).

In another embodiment, the invention provides a method that performs the process of the invention on a subscription, advertising, and/or fee basis. That is, a service provider, such as a Solution Integrator, could offer to provide predictive modeling-based resource allocation functionality. In this case, the service provider can create, maintain, support, etc., a computer infrastructure, such as computer system **12** (FIG. **1**) that performs the processes of the invention for one or more consumers. In return, the service provider can receive payment from the consumer(s) under a subscription and/or fee agreement and/or the service provider can receive payment from the sale of advertising content to one or more third parties.

In still another embodiment, the invention provides a computer-implemented method for predictive modeling-based resource allocation. In this case, a computer infrastructure, such as computer system **12** (FIG. **1**), can be provided and one or more systems for performing the processes of the invention can be obtained (e.g., created, purchased, used, modified, etc.) and deployed to the computer infrastructure. To this extent, the deployment of a system can comprise one or more of: (1) installing program code on a computing device, such as computer system **12** (FIG. **1**), from a computer-readable medium; (2) adding one or more computing devices to the computer infrastructure; and (3) incorporating and/or modifying one or more existing systems of the computer infrastructure to enable the computer infrastructure to perform the processes of the invention.

As used herein, it is understood that the terms "program code" and "computer program code" are synonymous and mean any expression, in any language, code, or notation, of a set of instructions intended to cause a computing device having an information processing capability to perform a particular function either directly or after either or both of the following: (a) conversion to another language, code, or notation; and/or (b) reproduction in a different material form. To this extent, program code can be embodied as one or more of: an application/software program, component software/a library of functions, an operating system, a basic device system/driver for a particular computing device, and the like.

A data processing system suitable for storing and/or executing program code can be provided hereunder and can include at least one processor communicatively coupled, directly or indirectly, to memory elements through a system bus. The memory elements can include, but are not limited to, local memory employed during actual execution of the program code, bulk storage, and cache memories that provide temporary storage of at least some program code in order to reduce the number of times code must be retrieved from bulk storage during execution. Input/output and/or other external devices (including, but not limited to, keyboards, displays, pointing devices, etc.) can be coupled to the system either directly or through intervening device controllers.

Network adapters also may be coupled to the system to enable the data processing system to become coupled to other data processing systems, remote printers, storage devices, and/or the like, through any combination of intervening private or public networks. Illustrative network adapters include, but are not limited to, modems, cable modems, and Ethernet cards.

The foregoing description of various aspects of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed and, obviously, many modifications and variations are possible. Such modifications and variations that may be apparent to a person skilled in the art are intended to be included within the scope of the invention as defined by the accompanying claims.

What is claimed is:

**1**. A computer-implemented method for provisioning computing resources using predictive modeling in a networked computing environment, comprising:

accessing a set of graphical curves of network data traffic versus time, the set of graphical curves being stored in at least one computer storage device;

segmenting the set of graphical curves into a set of predetermined time intervals to yield a set of time interval curves;

overlaying and fitting the set of time interval curves to yield a set of best fit overlaying curves;

generating a derivative vector plot based on a set of data points of the set of best fit overlaying curves; and

forecasting network traffic in the networked computing environment based on the derivative vector plot.

**2**. The computer-implemented method of claim **1**, further comprising provisioning a set of computing resources in the networked computing environment based on the forecasted network traffic.

**3**. The computer-implemented method of claim **1**, the derivative vector plot comprising a $K^{th}$ derivative vector plot being generated by transforming the set of data points using a mathematical algorithm.

**4**. The computer-implemented method of claim **3**, further comprising outputting a network traffic projection based on the forecasting.

**5**. The computer-implemented method of claim **4**, the network traffic projection being generated by integrating K initial conditions a K quantity of times using a predetermined numerical technique.

**6**. The computer-implemented method of claim **3**, the mathematical algorithm comprising a fourth order Runge-Kutta method.

**7**. The computer-implemented method of claim **1**, the networked computing environment comprising a cloud computing environment.

**8**. A system for provisioning computing resources using predictive modeling in a networked computing environment, comprising:

a memory medium comprising instructions;

a bus coupled to the memory medium; and

a processor coupled to the bus that when executing the instructions causes the system to:

access a set of graphical curves of network data traffic versus time, the set of graphical curves being stored in at least one computer storage device;

segment the set of graphical curves into a set of predetermined time intervals to yield a set of time interval curves;

overlay and fit the set of time interval curves to yield a set of best fit overlaying curves;

generate a derivative vector plot based on a set of data points of the set of best fit overlaying curves; and

forecast network traffic in the networked computing environment based on the derivative vector plot.

**9**. The system of claim **8**, the memory medium further comprising instructions for causing the system to provision a set of computing resources in the networked computing environment based on the forecasted network traffic.

**10**. The system of claim **8**, the derivative vector plot comprising a $K^{th}$ derivative vector plot, the memory medium further comprising instructions for causing the system to transforming the set of data points using a mathematical algorithm to yield the $K^{th}$ derivative vector plot.

**11**. The system of claim **10**, the memory medium further comprising instructions for causing the system to output a network traffic projection based on the forecasting.

**12**. The system of claim **11**, the network traffic projection being generated by integrating K initial conditions of a K quantity of times using a predetermined numerical technique.

**13**. The system of claim **10**, the mathematical algorithm comprising a fourth order Runge-Kutta method.

**14**. The system of claim **8**, the networked computing environment comprising a cloud computing environment.

**15**. A computer program product for provisioning computing resources using predictive modeling in a networked computing environment, the computer program product comprising a computer readable storage device, and program instructions stored on the computer readable storage device, to:

access a set of graphical curves of network data traffic versus time, the set of graphical curves being stored in at least one computer storage device;

segment the set of graphical curves into a set of predetermined time intervals to yield a set of time interval curves;

overlay and fit the set of time interval curves to yield a set of best fit overlaying curves;

generate a derivative vector plot based on a set of data points of the set of best fit overlaying curves; and

forecast network traffic in the networked computing environment based on the derivative vector plot.

**16**. The computer program product of claim **15**, the computer readable storage media further comprising instructions to provision a set of computing resources in the networked computing environment based on the forecasted network traffic.

**17**. The computer program product of claim **15**, the derivative vector plot comprising a $K^{th}$ derivative vector plot, the computer readable storage media further comprising instructions to transforming the set of data points using a mathematical algorithm to yield the $K^{th}$ derivative vector plot.

**18**. The computer program product of claim **17**, the computer readable storage media further comprising instructions to output a network traffic projection based on the forecasting.

**19**. The computer program product of claim **18**, the network traffic projection being generated by integrating K initial conditions a K quantity of times using a predetermined numerical technique.

**20**. The computer program product of claim **17**, the mathematical algorithm comprising a fourth order Runge-Kutta method.

**21**. The computer program product of claim **15**, the networked computing environment comprising a cloud computing environment.

**22**. A method for deploying a system for provisioning computing resources using predictive modeling in a networked computing environment, comprising:

providing a computer infrastructure being operable to:

access a set of graphical curves of network data traffic versus time, the set of graphical curves being stored in at least one computer storage device;

segment the set of graphical curves into a set of predetermined time intervals to yield a set of time interval curves;

overlay and fit the set of time interval curves to yield a set of best fit overlaying curves;

generate a derivative vector plot based on a set of data points of the set of best fit overlaying curves; and

forecast network traffic in the networked computing environment based on the derivative vector plot.

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